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Infrastructure Risk Reduction: The Case of Drinking Water Emergencies

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Infrastructure Risk Reduction: The Case Of Drinking Water Emergencies

by

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Abstract

Public water systems are an integral part of community infrastructure. Drinking water contamination or service disruptions have the potential to cause economic losses, limit fire suppression capability, and result in human illnesses. Until 2016, the United States federal government had not issued a disaster declaration due to contaminated water. The first federal drinking water disaster declaration due to contaminated water serves as a sentinel event demonstrating the need to increase focus on public water systems during all phases of emergency management: mitigation, preparation, response, and recovery. Previous studies evaluating risks to vulnerable populations associated with drinking water primarily utilized qualitative research techniques. This study compiles and analyzes data from three databases to quantitatively evaluate potential public water system characteristics that may lead to increased risk. Two of the three databases are maintained by the federal government, while the third is maintained by a nonprofit organization. Historically, it has been assumed that smaller systems and systems in disadvantaged communities would experience lower water quality. This study presents a method to quantitatively evaluate these types of hypotheses. This study evaluates data from public water systems within the states of Illinois and Texas. The results indicate that smaller water systems are more likely to receive regulatory violations than larger systems. In addition, the results suggest that communities with a higher social vulnerability index are more likely to experience elevated levels of nitrate.

Keywords: drinking water, social vulnerability, emergencies

Vita

Lieutenant Colonel Mark Paine was born in Pittsburgh, Pennsylvania. He is the son of Michael and Catherine Paine. Lt Col Paine received a Bachelor of Mechanical Engineering with a major in mechanical engineering and a minor in thermal engineering at the University of Dayton in 2001, a Master of Science in Management at Troy State University in 2005, and a Master of Science in Industrial Hygiene at Montana Technological University in 2010. He is also a Certified Industrial Hygienist through the American Board of Industrial Hygiene. Lt Col Paine was commissioned in the US Air Force Biomedical Sciences Corps as a Bioenvironmental Engineer and served in various assignments in the United States, Europe, and Asia. He remains on active duty with the Defense Health Agency and resides in Alexandria, Virginia.

Dedication

This dissertation is dedicated to my paternal grandfather, Michael Pacienza. He is a US Navy combat veteran from World War II and my hero.

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I would like to express my gratitude to my committee members: Dr. Tanveer Islam, Dr. Jane Kushma, and Dr. Alessandra Jerolleman. Additionally, I would like to thank my mentor, Dr. Thomas Augustine.

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Introduction

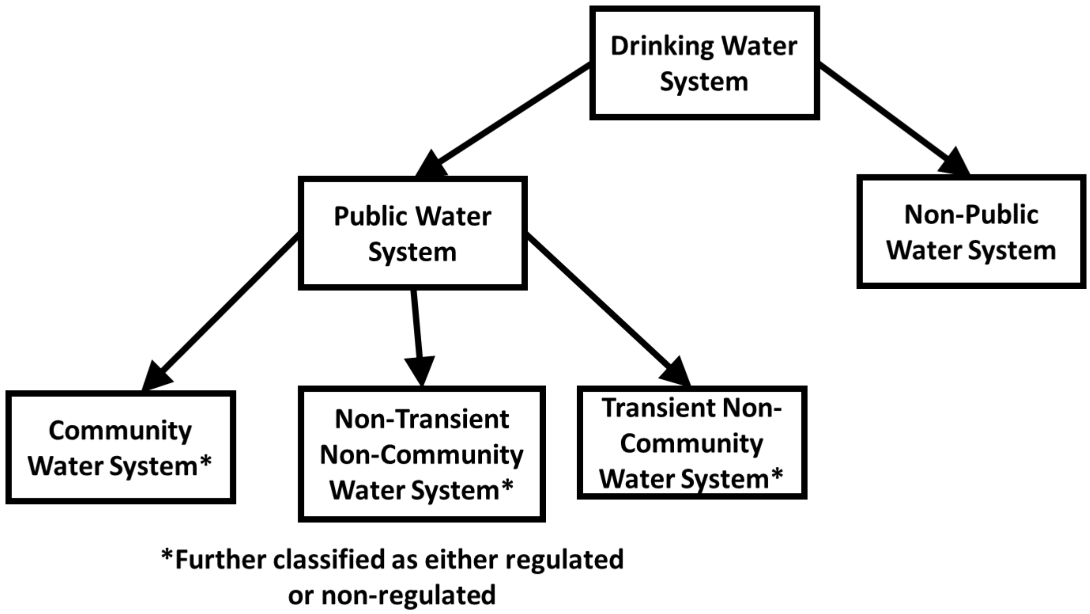
What is a disaster? The Stafford Act defines *major disaster* as “any natural catastrophe (including any tornado, storm, high water, wind-driven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, or drought), or, regardless of cause, any fire, flood, or explosion, in any part of the United States, which in the determination of the President causes damage of sufficient severity and magnitude to warrant major disaster assistance under this Act to supplement the efforts and available resources of States, local governments, and disaster relief organizations in alleviating the damage, loss, hardship, or suffering caused thereby” (Federal Emergency Management Agency, 2019b, p. 1). The Department of Homeland Security (DHS) has also released a broader definition of *disaster*, which it defines as an “adverse condition or occurrence that requires coordinated action across multiple entities and/or levels of government to resolve” (DHS, 2017, p. 178).

The International Association of Emergency Managers (IAEM) stated that the purpose of emergency management is to create “the framework within which communities reduce vulnerability to hazards and cope with disasters” (IAEM, 2007, p. 4). The Federal Emergency Management Agency (FEMA) reported that federal disaster declarations through 2015 have related to incidents such as terrorist attacks, fires, snowstorms, flooding, and severe storms (FEMA, n.d.). In 2016, a new type of disaster was declared for the first time--an incident in Flint, Michigan resulted in the first federal emergency declaration related to contaminated water (White House, 2016). The Flint incident confirmed that emergency managers may now be asked to consider or respond to threats to drinking water infrastructure. The new challenge for emergency managers is to develop techniques to optimally assess and mitigate potential hazards facing public water supplies.

How are drinking water systems structured in the United States? Drinking water systems each correspond to a regulatory classification, as depicted in Figure 1, which was originally published by Paine and Kushma (2017). In the United States, regulations under the Safe Drinking Water Act (SDWA) cover public water systems (PWSs). The SDWA excludes systems that do not meet the definition of a PWS. A PWS "provides water for human consumption through pipes or other constructed conveyances to at least 15 service connections or serves an average of at least 25 people for at least 60 days a year" (EPA, n.d.b, n.p.). Small systems, such as a household well, are not covered by the SDWA. Some schools, shopping malls, and trailer parks are considered PWSs. Ownership of a PWS may be either private or public. Approximately 90% of Americans receive drinking water through a PWS (EPA, n.d.b). PWSs are further divided and may be classified as a community water system, a non-transient non-community water system (NTNCWS), or a transient non-community water system. Notably, non-PWSs and unregulated PWSs are outside the scope of this case study.

Figure 1

Drinking Water System Classification



PWSs and their regulators differentiate between two types of source water—ground water and surface water. This bifurcated classification of source water was created for simplicity, as Winter et al. (1998) have outlined how ground water and surface water interact with one another and therefore are, in a larger sense, part of a single resource. The precise relationships between source water and ground water are beyond the scope of this study. The drinking water industry delineates between ground water and surface water and this study follows the same convention. Ground water is stored in aquifers beneath the Earth's surface and is pumped up through a drilled shaft for treatment. Surface water comes from lakes, reservoirs, rivers, or streams. Ground water is normally easier to treat because it is better protected. Surface water, due to excess dirt and dissolved particles, typically requires surface water treatment plants to have extra treatment processes (CDC, n.d.). The first extra treatment processes are coagulation and flocculation, which are "the clumping together of very fine particles into larger particles (floc)…[then] gathering [them] together…by a process of gentle mixing" (Sacramento State, 2017, p. 126). Another extra treatment process is sedimentation, which is the settling out of suspended particles.

The first recognition that drinking water could result in a public health disaster occurred in London in 1854 during a cholera outbreak. Dr. John Snow was able to pinpoint the source of the outbreak to a specific contaminated well (BBC, 2014). Large-scale efforts to treat water to prevent infection did not occur until 1908, when Jersey City became the first city to provide disinfection to its water supply (EPA, 2000). The U.S. Public Health Service (USPHS) released water quality standards in 1914, although they initially only applied to "interstate carriers like ships and trains, and only applied to contaminants capable of causing contagious disease" (EPA, 2000, n.p.). The USPHS updated their standards periodically, and were the de facto industry standard until the SDWA was enacted in 1974. The Centers for Disease Control (CDC) has attributed improvements in PWS operations as a major factor in the reduction of infectious diseases in the twentieth century (CDC, 1999).

The SDWA was amended in 1986 and 1996 and remains the framework for drinking water quality in the United States. Initially, the SDWA was focused on water treatment although the later amendments expanded into "source water protection, operator training, funding for water system improvements, and public information" (EPA, 2004, p. 1). This law enables US states to assert *primacy* enforcement responsibility of the SDWA within their own borders. States and territories that do not assert primacy receive SDWA enforcement from the United States Environmental Protection Agency (EPA). In this document, unless otherwise specified, the acronym Environmental Protection Agency (EPA) will refer to the federal-level EPA, as opposed to state-level equivalent agencies. Currently, all states and territories exert primacy except for Wyoming and the District of Columbia. The Navajo Nation also exerts primacy, although all other tribal lands receive SDWA enforcement from the EPA.

In addition to water quality, the federal government is in the process of implementing America's Water Infrastructure Act (AWIA) of 2018, which requires water systems "serving more than 3,300 people to develop or update risk assessments and emergency response plans" (EPA, n.d.a, n.p.). A key component of the new law is to identify and mitigate potential acts of human malevolence. In addition, it also addresses risks associated with improper technical management of PWSs. The new requirements include both risk assessments and emergency response plans. The AWIA, in combination with the SDWA, has resulted in the generation of assessments, tools, and reports that could be shared with emergency managers.

The AWIA (2018) affirmatively considers drinking water systems to be part of the American *infrastructure*. Additionally, FEMA (2019a) defined essential *community lifelines* as "those services that enable the continuous operation of critical government and business functions and are essential to human health and safety or economic security" (p. ii). PWSs may therefore be considered as both critical infrastructure and as essential community lifelines. PWSs, as such, have a relationship with emergency management professionals. However, the specific role of emergency managers with respect to PWSs remains ambiguous. This study explores the body of emergency management literature that may facilitate a better understanding of the relationship between emergency managers and PWSs.

What defines a health hazard that must be addressed through a governmental response? The federal regulations that implement the SDWA (1974) defined conditions that constitute a health hazard in 40 CFR Part 141—*National Primary Drinking Water Regulations*. Additionally, state governments that maintain primacy for the SDWA may publish more stringent state-level guidance. Operators of water treatment facilities must be licensed and, as such, utilize trained personnel and are legally bound to protect the public. The Environmental Working Group (EWG), has suggested that the federal regulations are not sufficiently stringent to protect human health (EWG, 2019). Additionally, many communities have difficulty implementing the regulations. Organizations such as the National Rural Water Association work to provide technical assistance to these communities (NRWA, n.d.).

Incidents involving drinking water that have the potential to impact human health occur on a routine basis. However, there had never been a federal emergency declaration for "water contamination" until 2016 (FEMA, n.d., n.p.). How have threats to drinking water historically been managed? This question also applies to how current drinking water threats, which do not rise to the level of a declared emergency, are handled. *Health advisories* are issued when "water quality is or may be compromised" (CDC, 2016, p. 10). Alternately, a *health notification* is more serious and is triggered by specifically-defined regulatory violations or an actual disease outbreak (EPA, n.d.c). In some cases, natural disasters such as hurricanes or floods may severely damage drinking water systems. These situations will typically result in a declared emergency, although the emergency is not directly attributed to a degraded water system. The novel aspect of the Flint emergency is that *contaminated water* was the stated cause of the emergency declaration.

The quantitative portion of this study focuses on Texas and Illinois. Why does the quantitative portion of this study focus on these two states? The SDWA (1974) is enforced at the state level. Therefore, comparing data regarding regulatory violations across state lines may contribute to a loss of face-validity. Texas and Illinois were selected among the fifty states because they are large, diverse, and provide the public with large amounts of information and data. At least eight states both utilize propriety software to aggregate drinking water sampling data and publically display the resulting information. The eight known states are: Texas, California, Louisiana, Rhode Island, Alaska, New Jersey, North Carolina, and Illinois. Texas and Illinois are large states, and they possess a diverse array of communities with respect to the Centers for Disease Control social vulnerability index (SVI). Texas and Illinois provide the public access to drinking water quality data associated with specific PWSs (TCEQ, n.d.; IEPA, n.d.).

Problem Statement and Purpose of the Study

The broad *problem* that this study seeks to address is that drinking water safety is at risk globally although the risks are not well understood and emergency management professionals have not historically sought to reduce those risks. What does it mean to state that the *risks are not well understood*? It means that meta-data has not yet been analyzed to determine the causes of negative PWS outcomes—increased regulatory violations or elevated contaminant levels. This case study seeks to quantitatively assess potential relationships between various parameters and negative PWS outcomes. For example, it is generally assumed that socially vulnerable communities would have elevated contaminants in their water. This case study seeks to quantitatively evaluate the data to make a determination.

What does it mean to state that emergency managers have not historically sought to reduce risks associated with PWSs? A FEMA (n.d.) publication indicates there has never been a federally recognized disaster attributed to a PWS in the United States until 2016. When PWSs place their populations at risk, they are statutorily responsible for executing all of the risk communication to the public in conjunction with the primacy agency (SDWA, 1974). Absent formal disaster declarations, which are extremely rare, there are no formal mechanisms to utilize emergency management professionals to participate in risk communication associated with PWS failures.

The negative outcomes that are assessed quantitatively by this case study are regulatory violations and elevated contaminant levels. However, this case study also discusses non-routine engineering upgrades that have the potential to impact the community. Currently, no databases are available that contain applicable meta-data associated with major engineering upgrades to PWSs. Therefore, incidents such as the one that occurred in Flint are reviewed from the qualitative, rather than the quantitative, perspective. The Flint disaster occurred during a major project to procure raw water from a different source—it was not initiated through the failure of existing procedures and equipment. Research for this case study did not identify any other recent examples of a city the size of Flint changing its source of raw water on a compressed timeline.

All aspects of potential risks to the water supply are worthy of evaluation by emergency managers. Meta-data, when available, can be evaluated to assess risks. In addition, when engineering projects fail, such as in Flint, they should be qualitatively evaluated to seek lessons learned. This paper evaluates both quantitative and qualitative data to identify methods to reduce risk during mitigation, preparedness, response, and recovery. Emergency managers in the present and future may be concerned with all risks to their communities, including risks associated with PWSs.

Integration of the mitigation and preparedness phases of emergency management associated with PWSs has been addressed by a number of EPA publications. A primary method of mitigating disasters associated with PWSs is to assure that water operators have proper training and certification. The system of training and certification is non-standard in that each state has its own regulations. The EPA has provided a *Summary of State Operator Certification*

Programs which helps explain the complicated system, although there are no plans to reduce complexity within the system (EPA, 2016b). Drinking water operators work with professional engineers, whose certifications are also issued at the state-level. Mitigation and preparedness tools also include a variety of checklists issued by the EPA, such as the *Incident Action Checklist--Flooding* (EPA, 2015a).

Response and recovery to PWS disasters remain largely under the regulatory umbrella of the SDWA. In this sense, PWSs and primacy agencies follow the SDWA rather than regulations that flow through emergency management channels. However, the federal government has issued non-binding guidance on how PWSs and emergency managers are able to increase communication and work more closely together (EPA, 2018). For example, the EPA (2018) publication *Connecting Water Utilities and Emergency Management Agencies* recommends how PWSs and emergency managers can increase information sharing.

The introduction to this study provided an overview of PWSs and how non-emergency managers have historically provided risk reduction techniques. The introduction also included the stated goals of emergency managers and demonstrated that reducing risk associated with PWSs is included within the scope of emergency management. There are a number of technical and administrative *problems* that contribute to increased risk associated with PWSs. However, the main *problem* that this study is addressing is the emergent nature of the relationship between emergency management and PWSs.

This study is predicated on the assumption that the current level of risk to drinking water is sufficient to justify a maturation of the relationship between emergency management and PWSs. It is possible that, due to issues such as aging infrastructure, PWSs may face increased risk in the future. Additionally, this study evaluates the relationship between social vulnerability and drinking water risk. If social vulnerability is related to risk, then future trends associated with social vulnerability may increase the need for improved relationships between emergency managers and PWSs. Overall, future trends associated with drinking water risk are likely to be jurisdiction-dependent. For example, the state of California, through Senate Bill 1398 (2016), are pursuing legislation to eliminate all lead service lines within their border.

The nature and quantity of resources and methodologies by which communities mitigate, prepare, respond, and recover from drinking water-related emergencies is evolving. This research effort is a case study to identify potential methods of reducing risks associated with PWSs. The first goal is to quantitatively evaluate meta-data, focusing on two particular states, to potentially identify relationships that may facilitate risk assessments of PWSs. The second goal is to conduct a review of existing literature related to emergency management in order to ascertain existing mitigation, preparedness, response, and recovery techniques and strategies. In addition to the academic publications such as those cited in this study, the literature includes governmental resources. A preliminary pull of governmental documents to prepare this study resulted in the identification of 212 relevant resources totaling 6,761 pages. Example tiles of these documents include *Memorandum of Understanding Between the United States Environmental Protection Agency and the Department of Homeland Security Federal Emergency Management Agency* (DHS & EPA, 2019), *Inventory of EPA's Tools for Enhancing Community Resilience to Disasters* (EPA, 2016a), and *Connecting Water Utilities and Emergency Management Agencies* (EPA, 2018).

Significance of the Study

The four phases of emergency management are mitigation, preparedness, response, and recovery (National Governors' Association, 1979). This case study explored methodologies, expressed in the literature, by which both PWSs and emergency managers engage throughout each phase of emergency management. An overview of these methods may assist emergency managers developing plans for their communities. In addition, three diverse datasets were quantitatively assessed. This case study performed data analyses to explore potential improvements to conducting vulnerability assessments. Meta-data from the existing large datasets has not been widely analyzed. An exception was reported by Fedinick et al. (2019), who evaluated the data from a social justice perspective. If relationships are identified among key variables within the present study, then future research could be conducted to better explore the phenomena.

This study aimed to identify existing techniques that emergency managers and water utilities utilize to reduce risk throughout the four phases of emergency management. Areas for increased collaboration were also identified. According to the SDWA (1974), PWSs assume primary responsibility for all four phases of emergency management while primacy agencies provide oversight. In the future, emergency managers may need to respond when public utilities and primacy agencies fail in their basic duty to protect consumers. Increased collaboration between emergency managers and PWSs may facilitate better outcomes for communities.

The incident in Flint, Michigan, was somewhat of a unique case, not just in the magnitude of the impact on the community, but also in the sense that the proximate cause was a switch to a new type of source water. This is not a frequent occurrence, as research for this case study did not find any other recent examples of a PWS serving nearly 100,000 persons switching their water source on a compressed timeline. While there is nothing inherently illegal or improper about switching water sources, the project in Flint resulted in criminal charges against individuals involved in the process (Booker, 2021). The project failed from an engineering perspective, and there was also an apparent cover-up that prevented earlier detection of the failure (Egan, 2015). The apparent cover-up involved the state-level primacy agency as well as the local PWS, which was also under management of the state government (Egan, 2015).

This case study is based, in part, on the assumption that there is room for improvement in how communities manage such projects. Federal and applicable state regulations stipulate the responsible parties in such projects—and it's not emergency managers. This study, in accordance with supporting literature, is based on the assumption that emergency managers can, however, play some role, as opposed to no role. This study seeks to better delineate what that role may entail with respect to mitigation, preparedness, response, and recovery.

This case study considers different types of drinking water-related emergencies that may occur. Some water-related emergencies do not result in declared emergencies. These types of incidents therefore not require immediate public notification. This may occur, for example, when water sampling indicates a parameter exceeds a trigger level. Public reporting of these incidents typically occurs once per year in the annual Consumer Confidence Report, as opposed to real-time notification. The next type of incident requires immediate public notification, but will not result in a declaration of emergency. An example would be significant contamination levels resulting from a backflow incident or operational error. An example of a third type of water-related emergency is a natural disaster that tangentially threatens the drinking water supply, for example through damaged infrastructure or flooding. Flint, Michigan, was an example of a new type of emergency—a declared emergency specifically relating to drinking water contamination.

Historically, drinking water incidents have not been managed under the auspices of emergency management. Instead, the framework for mitigation, preparation, response, and recovery has been guided for the last approximately half-century under the regulatory framework of the SDWA. Governmental publications and academic literature have emerged over the decades that allude to a more comprehensive approach to reducing risk associated with public water supplies. The EPA has directly made some recommendations on how emergency managers and PWSs can better work together (EPA, 2018). This case study operated on the premise that ambiguity remains as to how emergency managers can best facilitate reductions in risk to their water supplies.

Emergency managers have, as discussed in the introduction, not historically been participants in risk reduction efforts related to drinking water systems. In 2016, a federal disaster was declared due to contaminated water. Given the stated purpose of emergency management cited in the introduction, emergency managers cannot ignore disasters related to drinking water. A key problem is that emergency management-related techniques to address drinking water systems are still emerging. This paper seeks to utilize both quantitative and qualitative techniques to ascertain how emergency managers can more successfully mitigate, prepare, respond, and recover to drinking water incidents.

The academic literature, as well as government documents, provide information regarding risk reduction associated with drinking water systems (EPA, 2014b; Switzer & Teodoro, 2018). In addition, large data sets of drinking water-related data are publicly available, from both public and private sources. This case study reviews the literature and quantitatively assesses the datasets. This study provides an overview of the literature as well as an outline of the methodology by which the quantitative data can be analyzed.

Why is this study going to focus on data from Texas and Illinois? The SDWA is enforced at the state level. Therefore, comparing data regarding regulatory violations across state lines may add a degree of uncertainty to the results. At least eight states both utilize propriety software to aggregate drinking water sampling data and publically display the resulting information. The eight known states are: Texas, California, Louisiana, Rhode Island, Alaska, New Jersey, North Carolina, and Illinois. Texas and California are the largest states, and therefore provide the most data points. Texas was selected for this study instead of California for two reasons. First, it possesses a more diverse array of communities with respect to the Centers for Disease Control SVI. Second, Texas provides more public information regarding its drinking water program. The availability of additional information is likely to enhance the analysis of quantitative findings. Illinois was selected because of its healthy mix of ground water and surface water.

The Role of Environmental Justice

The body of environmental justice literature relating to drinking water and its associated infrastructure has been growing in recent years (Fedinick et al., 2019; Switzer & Teodoro, 2018; Balazs & Ray, 2014). The 2016 Flint, Michigan disaster appears to have been a focusing event which provided increased attention to drinking water systems among researchers. A number of these studies have particular relevance to social vulnerability and drinking water systems. Two parameters were the focus of these studies. First, regulatory violations were analyzed. Second, data associated with drinking water contaminants was studied. The results associated with these two parameters were then compared with various indicators of social vulnerability such as race, income, language spoken, or SVI. The CDC formally defines SVI as “the potential negative effects on communities caused by external stresses on human health” (ATSDR, n.d., n.p.).

Fedinick et al. (2019) published the results of a multi-organizational study that researched the linkage between drinking water violations and factors associated with vulnerability. The report used descriptive data comparisons, rather than inferential statistical analyses, to evaluate the quantitative data. The primary conclusion was that regulatory “violations were more likely in counties with racial, ethnic, and language vulnerability and subpar housing and transportation quality” (p. 35). An article by Fedinick et al. (2019) was one of the few environmental justice articles that specifically noted that distribution systems, in addition to treatment systems, require attention with respect to risk mitigation efforts.

Switzer and Teodoro (2018) touched on a subject that may benefit from an expanded analysis: local management of drinking water systems. Much like school districts, funding is primarily local even if funding from higher levels of government may be available as a supplement. In this sense, there is no federal or state-level drinking water system. States provide regulatory oversight over systems, but they do not own or operate the systems. Switzer and Teodoro (2018) discussed the implications of the local nature of PWSs. In addition, they specifically addressed the issue of which specific parameters of social vulnerability were most influential with respect to drinking water: class and race.

Several environmental justice articles (McDonald & Jones, 2018; Balazs & Ray, 2014) discussed governmental interfaces with PWSs. The structure of local governments, funding schemes, and oversight procedures all contribute to the overall effectiveness of PWSs. McDonald and Jones (2018) included a discussion of EPA involvement with environmental justice. Additionally, they discussed Government Accountability Office efforts and recommendations to improve accuracy of the EPA Safe Drinking Water Information System (SDWIS) (General Accountability Office, 2011). Balazs and Ray (2014), proposed a “Drinking Water Disparities Framework” as an archetype for the drinking water industry (p. 603). The Balazs and Ray model centered PWSs within three different types of environments: the natural environment, the built environment, and the sociopolitical environment.

All of the articles reviewed in this section, with the exception of Switzer and Teodoro (2018), directly addressed the role of system size (as measured by population served) with respect to negative outcomes for drinking water systems. In each case, small systems were noted for having limited access to what Balazs et al. (2012) termed "technical, managerial and financial (TMF) capacity" (p. 9). Balazs et al. (2011), in a study involving nitrate concentrations, found that "[f]or large systems, we did not find significant associations between race/ethnicity or home ownership and nitrate levels" (p. 1276). This is interesting, in that it suggested that larger systems may be able to overcome challenges associated with increased social vulnerability through TMF capacity. This case study considers SVI as one potential factor of negative outcomes, and it also evaluates other potential sources of negative outcomes.

The negative outcomes that were quantitatively measured in the environmental justice studies were of two general types: regulatory violations or contaminant levels. Balazs et al. (2011) explicitly discussed, in reference to "both components of environmental justice," "compliance challenges as well as exposure to contaminants" (p. 2). There are multiple types of regulatory violations, some of which are health-based and others which are not. For example, a violation could be issued for failure to make proper notifications of certain events. In addition to *contaminants*, a number of physical parameters may be water quality indicators. For example, turbidity and pH are not contaminants but they do impact drinking water quality. All of the studies evaluated restricted their analysis to contaminants, which are defined by 20 CFR part 141 (2021) as "any physical, chemical, biological, or radiological substance or matter in water." This case study uses the convention of other studies, and focuses on indicators, rather than restricting the evaluation to contaminants.

Relationships between Water Utilities and Emergency Managers

The EPA has published multiple documents to assist PWSs with respect to disasters. For example, a guide to mitigating against floods has been released (EPA, 2014b). Flooding is a relatively common occurrence and it may occur simultaneously with a major natural disaster that forces resources to be dispersed throughout the community. In addition, the AWIA guidance can be used to identify potential threats which require mitigation (EPA, 2019a). Additional guidance on potential mitigation requirements can be found in other documentation, such as the *System Measures of Water Distribution System Resilience* (EPA, 2015b).

In this document, unless otherwise specified, the acronym Environmental Protection Agency (EPA) will refer to the federal-level EPA, as opposed to state-level equivalent agencies. The EPA has published a guide for how “water utilities and emergency management agencies can work together to better respond to emergencies” (EPA, 2018, p.1). This document primarily gave suggestions on how water utilities and emergency managers can develop relationships to facilitate collaboration during responses. For example, joint participation in training exercises and tours of each other’s facilities were recommended. Shared administrative processes were also discussed, such as providing water utilities space in emergency operations centers and providing responder access badges to utility workers. Joint effort on emergency communication to the public was also suggested.

The EPA (2018) also recommended joint planning to assist both in the mitigation and preparedness phases of emergency management. This included sharing emergency response plans, emergency operations plans, and county hazard mitigation plans. The focus of joint planning efforts is to manage emergency water scenarios, with a particular focus on alternate drinking water sources. Combined efforts may also enhance the mitigation phase of emergency management. For example, if a water utility identifies a particular vulnerability, then funding sources could be pursued as a team.

Primacy agencies are typically run by state governments, normally through the equivalent of a state-level EPA. Such agencies may have a variety of names, such as *Department of Environmental Protection* or *Environmental Protection Agency.* The EPA has published guidance for state-level EPAs to mitigate, prepare, respond, and recover from water-related emergencies (EPA, 2013b). Mitigation guidance is geared toward utilizing existing funding opportunities. However, no recommended methods of identifying hazards were suggested in the document. For example, there was no recommendation to utilize data from sanitary surveys to feed into the mitigation process. The remainder of the suggestions in the 2013 EPA guidance related to developing specific response and recovery plans and checklists.

The EPA (EPA, 2014a) has provided some guidance regarding how to implement physical security measures to defend against malicious tampering with the water supply. Basic recommendations included fencing, locks, and proper lighting. Enhanced guidance was provided to assist water utilities to implement the AWIA. Later, the EPA (2019a; 2019b) produced additional guidance to protect against malevolent acts against PWSs. This recent guidance was more comprehensive in that it covered all aspects of security, including natural disasters and cyber-attacks. The EPA also supported a Water Network Tool for Resilience that assists with all aspects of maintaining operations at a PWS (Klise et al., 2017). Guidance has also been published regarding remote sensing of water systems as early warning for contamination (EPA, 2016a).

The federal government provides substantial guidance for the response phase of emergency management. For example, the EPA has published a detailed “Incident Action

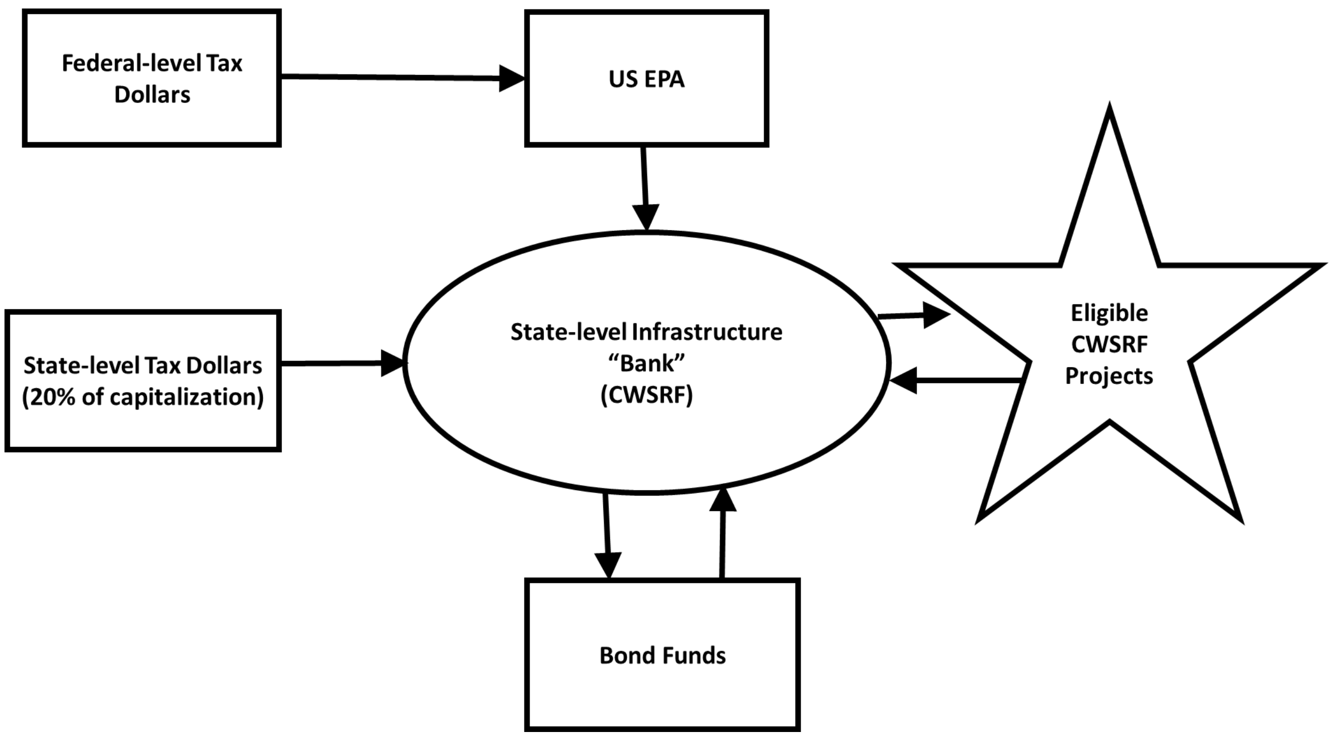
Checklist" for flooding (EPA, 2015a, p. 1). Additionally, guidance is available for the emergency disinfection of water (EPA, 2017). If proper planning is completed, then the response phase of a water emergency can be straightforward. Difficulty may arise, however, when communities do not properly plan or if they plan for the wrong scenarios. In addition to responding to emergencies, proper communication to the public is critical. The CDC has published guidance to assist PWSs with this type of communication (CDC, 2016).

On June 4, 2019, the EPA and FEMA released a memorandum of understanding (MOU) to address funding associated with PWSs after a disaster (EPA, 2019b). The primary goal of the MOU was to increase the speed with which funding is made available to the community to begin recovering. Previously, the money would have needed to be fronted; then, assistance could be applied for after the fact. The new arrangement quickly makes loans available to pay for recovery. The loans must be matched by the state. The partnership between the EPA and FEMA works through the existing framework of state revolving funds, which are depicted schematically in Figure 2.

The EPA Clean Water State Revolving Fund (CWSRF) was authorized by the Clean Water Act amendments (1987). The CWSRF made two fundamental changes to the way the federal government assisted funding of local water projects. First, instead of grants, the program began issuing primarily loans. Second, states were placed in charge of managing their programs instead of the federal government. Federal funds were applied to the programs, then states fund a 20% match. The EPA refers to "51 state-level infrastructure 'banks'" that issue loans for projects (EPA, 2015c, p. 5). Their operation is shown in Figure 2 below, adapted from the EPA (2015c).

Figure 2

Clean Water State Revolving Fund Cash Flows



Literature Review

Large technical systems (LTSs) consist of infrastructure that enable "a myriad of social changes, for good or worse" (Van der Vleuten, 2004, p. 396). LTSs are large-scale networks responsible for functions such as power production or the provision of drinking water (Roe et al., 2004). LTSs encompass multiple organizations and are not represented by a single project, company, or governmental entity. Anticipation, recognition, evaluation, and control of risk within an LTS requires analysis of technical, social, and organizational factors (Kleiner et al., 2015).

LTSs are multi-organizational institutions that provide vital services to the societies that they serve (Perrow, 1999). Drinking water systems, based upon Perrow's definition, are one type of LTS. LTSs require an established cadre of reliability professionals to assure reliability on behalf of the public (Perrow, 1999). Several theories, such as normal accident theory (NAT) and high reliability theory (HRT) have developed to analyze and assure the reliability of LTSs. NAT theorizes that failures are inevitable while HRT suggests that failures can be largely prevented (Perrow, 1994, La Porte, 1994). The failure of a drinking water system can result in a public emergency, as evidenced by the 2016 disaster in Flint, Michigan. Trained reliability professionals are required to mitigate, prepare, respond, and recover from emergencies.

Drinking water utilities, similar to fires, present potential risk to communities. However, fires are much more likely to result in declarations of emergency when they cause extensive damage. This literature review discusses the role of water utilities within the framework of disasters. Drinking water systems may result in disaster when they are disrupted, contaminated from the source, or during backflow incidents. Each phase of emergency management must be considered with respect to drinking water systems.

The design, maintenance, and oversight of LTSs requires a diverse cadre of reliability professionals. Reliability professionals may have requirements such as education, training, experience, or professional certification. Building codes, legal requirements, and professional codes of ethics are some of the structures which govern reliability professionals that work with LTSs. A duty to protect the public safety is inherent in these professions, and failures may entail severe consequences. Examples of reliability professionals within the drinking water industry include professional engineers, governmental regulators, and drinking water system operators.

A partial meltdown of a nuclear reactor at Three Mile Island in Middletown, Pennsylvania in 1979 was “the most serious accident in U.S. commercial nuclear power plant operating history (Nuclear Regulatory Commission, 2018, p.1).” In 1981, a book titled *Accident* *at Three Mile Island: The Human Dimensions* (Sills et al., 1981) on the human aspects of the situation was published. Two contributors to the book, Charles Perrow and Todd La Porte, later developed different theories relating risk reduction within LTSs (Rijpma, 1997). Perrow (1994) focused on the framework within which LTSs operate and La Porte (1994) worked toward techniques to minimize risk.

Perrow (1999) proposed the Normal Accident Theory (NAT) in a text regarding safety risks of LTSs. Perrow (1999) viewed the occurrence of accidents as a normal part of an LTS lifecycle. Perrow considered two attributes of LTSs as being directly proportional to their risk level: complexity and tight coupling. Complex systems are difficult to understand, manage, and control. Tightly coupled systems enable errors to quickly compound when problems emerge. According to Perrow, LTSs that are complex and tightly coupled will inevitably result in periodic failures.

La Porte, working with a team at the University of California, Berkeley, developed what later became known as HRT (Rijpma, 1997). Their initial progress stemmed from case studies among the air traffic control system, electric power generation, and naval operations (Morgan, 2017). Christianson et al. (2011) distilled the five main tenants of highly reliable organizations: “preoccupation with failure…, reluctance to simplify…, sensitivity to operations…, resilience…, and deference to expertise” (p. 314).

The Flint, Michigan drinking water crisis was an example of an LTS failure. The disaster demonstrated, for the first time, that impaired drinking water quality may result in a declared emergency. Drinking water quality may be compromised by a variety of threats. Threats may include the following: natural disasters, seasonal weather changes, failure to conduct proper operations and maintenance, chemical contamination, terrorism, or cyber-attacks . Natural disasters may increase the risk to water systems through large-scale flooding and industrial-scale contaminant releases. The methods by which drinking water risk reduction is incorporated into the four phases of emergency management are still emerging.

Theoretical analysis of the breakdown of LTSs can be performed through both NAT and HRT. NAT and HRT were developed in the 1980s, and continued to be refined in the 1990s and beyond. NAT holds that accidents are inevitable in systems that are complex and tightly coupled. HRT attempts to work in a complement with NAT and seeks to reduce risk to the greatest degree possible. The drinking water industry has existing methods of mitigating, preparing, responding, and recovering from disasters. Increasing relationships and information-sharing between water utilities and emergency managers may reduce risk in the future.

Methods

The existing literature associated with both drinking water infrastructure and environmental justice have informed this case study. Quantitative analysis of environmental justice has become simplified through the development of the SVI. This study differs in its quantitative analysis from previous research in four different ways. First, parameters for violations are analyzed on both a raw and a per-capita basis. Second, this case study encompasses two entire states and will exclude data from outside of those states. Studies cited in the literature have typically analyzed either national data or localities smaller than a state. Data is restricted to the state-level in this study because enforcement primacy and other significant water-related programs operate at the state level. Third, this case study analyzes factors such as source water type, number of regulatory site visits, and utilize multiple measures of system size. In particular, analyses are performed for system size both based on PWS population served and by number of facilities. Fourth, the case study factors both types of negative outcomes—

regulatory compliance and contaminant levels. No Institutional Review Board approvals were required for this case study, as there was no research involving human or animal test subjects.

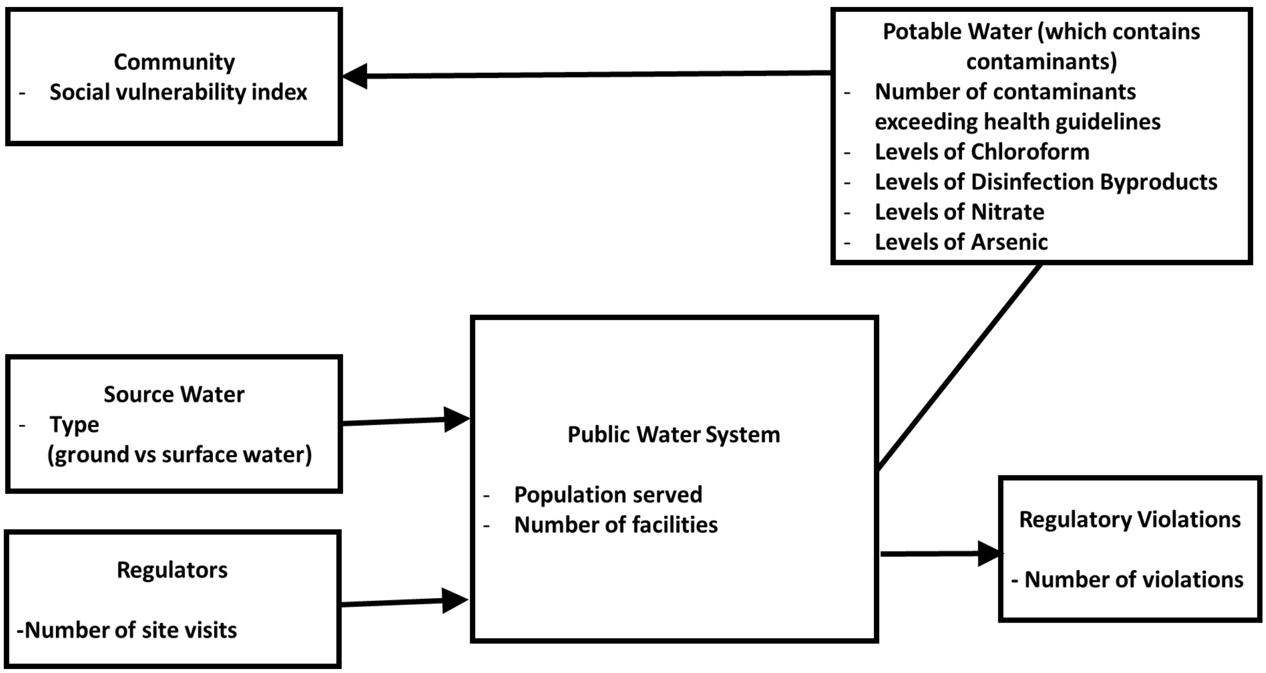
Methodology

The purpose of this case study was to identify methods of risk reduction associated with drinking water emergencies and disasters. A qualitative review of the literature was conducted to identify existing emergency management techniques to mitigate, prepare, respond, and recover from incidents. Additionally, a dataset has been compiled from portions of three large data repositories. The dataset has been quantitatively analyzed to determine potential relationships that could enhance water-related risk reduction efforts. The conclusion of the case study reveals both implications and areas of future research.

This case study was based upon the conceptual framework in Figure 3 that describes relationships between key nodes associated with drinking water infrastructure. The conceptual framework is presented in Figure 3. PWSs treat raw water, whether ground or surface water, and are overseen by regulators. PWSs produce potable water for consumers. Potable water is not pure, and normally contains low levels of contaminants. PWSs may generate regulatory violations, by producing excess levels of contaminants or by other actions such as improper management. The communities that consume water from a PWS may be characterized based upon their social vulnerability. This case study utilized the CDC SVI as the measure of social vulnerability.

Figure 3

Conceptual Framework



PWSs are part of the American infrastructure, and they are responsible for delivering potable water to communities. Disruption to the supply of potable water may indirectly result from disasters. However, disruption to the supply of potable water caused by a PWS could also independently create an emergency. The conceptual framework provides a simplified overview of the parameters that may be related to PWS risk levels. This study utilized three existing databases to evaluate the relationship between each of the parameters and negative outcomes.

Research Question

How can emergency managers improve risk reduction efforts associated with drinking water infrastructure through analysis of practices and meta-data within the emergency management literature?

Hypotheses

Hypotheses Group 1: Social Vulnerability

The first group of hypotheses tests whether there is a relationship between social vulnerability and ten other factors. Each of those relationships has a separate null hypothesis, listed below. (Hypotheses with an asterisk* only apply for PWSs with a population of 10,000 or greater due to limited data availability.) The ten null hypotheses are as follows:

- There is no relationship between SVI and population served.
- There is no relationship between SVI and quantity of regulator site visits.
- There is no relationship between SVI and quantity of regulator site visits per capita.
- There is no relationship between SVI and regulatory violations.
- There is no relationship between SVI and regulatory violations per capita.
- There is no relationship between SVI and number of contaminants exceeding health
- guidelines*.
- There is no relationship between SVI and levels of chloroform*.
- There is no relationship between SVI and levels of disinfection byproducts*.
- There is no relationship between SVI and levels of nitrate*.
- There is no relationship between SVI and levels of arsenic*.

The null hypotheses were created to test the relationship between SVI and other factors. The formulation of the null hypotheses is not intended to prejudge whether the hypotheses will be accepted or rejected. Social vulnerability could possibly be related to the attention of regulators and therefore water quality. Regulator attention can be tracked based on the number of site visits made to each PWS. It is also possible to track and analyze the number of regulatory violations that are assigned to each PWS. Water quality may also be impacted by the degree of community vulnerability. It is not possible to fully determine the impact of social vulnerability on regulatory attention or water quality without quantitatively evaluating the data.

Regulator attention to PWSs can be evaluated though the use of metrics. Regulatory violations track identified problems attributed to a PWS. It is possible that vulnerable communities have more violations due to lack of ability to self-fund their PWSs. However, it is also possible that vulnerable communities have fewer violations because regulators do not bother to show up to their facilities in order to provide an evaluation. There is no available data to track violations that were not identified by regulators. However, it is possible to track the number of regulatory visits that were received by each PWS. A quantitative analysis will determine the relationship between community vulnerability and the both number of regulatory site visits and the number of violations.

Water quality data is available and can be analyzed based on the associated social vulnerability index. However, until the data is analyzed it is not possible to know if any relationships exist. It is possible that vulnerable communities have lower water quality. However, it is also possible that wealthy areas have worse water quality. Poor water quality may be an indicator of a current or past industrial base that provides (or provided) a robust economy. In that case, poor water quality may essentially be a tradeoff for a more favorable social vulnerability index. It is also possible that due to regulations all communities have a similar level of water quality.

Hypotheses Group 2: Source Water Type

The second group of hypotheses tests whether there is a relationship between source water type and nine other factors. Each of those relationships has a separate null hypothesis, listed below. (Parameters with an asterisk* only apply for PWSs with a population of 10,000 or greater due to limited data availability.) The nine null hypotheses are as follows:

- There is no relationship between source water type and quantity of regulator site visits.
- There is no relationship between source water type and quantity of regulator site visits per capita.
- There is no relationship between source water type and number of violations.
- There is no relationship between source water type and number of violations per capita.
- There is no relationship between source water type and number of contaminants exceeding health guidelines*.
- There is no relationship between source water type and levels of chloroform*.
- There is no relationship between source water type and levels of disinfection byproducts*.
- There is no relationship between source water type and Levels of nitrate*.
- There is no relationship between source water type and levels of arsenic*.

Only 2.5% of Earth's water is freshwater (United States Geological Survey, n.d.). "Precipitation is the ultimate source of all fresh-water resources, [although] most of it never enters an aquifer or runs off into a stream" (Foster, 1988, p. 6). A significant portion of precipitation is evaporated back into the atmosphere and much of it is also captured by vegetation and then released through transpiration. Precipitation that saturates below the water table is available for use as ground water.

It is possible that ground water will have fewer contaminants and fewer violations because it is better protected from the environment. However, it is also possible that modern practices will enable surface water to achieve the same levels of water quality as surface water. It is also possible that because surface water is more complex to treat that those systems will be more prone to regulatory violations.

Hypotheses Group 3: PWS System Size (measured by population served)

The third group of hypotheses tests whether there is a relationship between PWS system size (measured by population served) and ten other factors. Each of those relationships has a separate null hypothesis, listed below. (Parameters with an asterisk* only apply for PWSs with a population of 10,000 or greater due to limited data availability). The ten null hypotheses are as follows:

- There is no relationship between PWS system size (measured by population served) and quantity of regulator site visits.
- There is no relationship between PWS system size (measured by population served) and quantity of regulator site visits per capita.
- There is no relationship between PWS system size (measured by population served) and number of violations.
- There is no relationship between PWS system size (measured by population served) and number of violations per capita.
- There is no relationship between PWS system size (measured by population served) and social vulnerability index.
- There is no relationship between PWS system size (measured by population served) and number of contaminants exceeding health guidelines*
- There is no relationship between PWS system size (measured by population served) and levels of chloroform*

- There is no relationship between PWS system size (measured by population served) and levels of disinfection byproducts*
- There is no relationship between PWS system size (measured by population served) and levels of nitrate*
- There is no relationship between PWS system size (measured by population served) and Levels of arsenic*

Larger PWSs typically have access to more resources and larger technical staffs. It is therefore possible that larger PWSs therefore have higher water quality and fewer regulatory violations. Several metrics are available to determine the size of a system. The population served is one determinant of the size of a PWS. It is possible, given a common regulatory framework, that all systems will produce a similar quality of water. It is also possible that the size of a system is unrelated to the number of regulatory violations.

Hypotheses Group 4: PWS System Size (measured by number of facilities)

The fourth group of hypotheses tests whether there is a relationship between PWS system size measured by number of facilities) and ten other factors. Each of those relationships has a separate null hypothesis, listed below. (Parameters with an asterisk* only apply for PWSs with a population of 10,000 or greater due to limited data availability.) The ten null hypotheses are as follows:

- There is no relationship between PWS system size (measured by number of facilities) and Quantity of regulator site visits
- There is no relationship between PWS system size (measured by number of facilities) and Quantity of regulator site visits per capita

- There is no relationship between PWS system size (measured by number of facilities) and Number of violations
- There is no relationship between PWS system size (measured by number of facilities) and Number of violations per capita
- There is no relationship between PWS system size (measured by number of facilities) and Social vulnerability index
- There is no relationship between PWS system size (measured by number of facilities) and Number of contaminants exceeding health guidelines*
- There is no relationship between PWS system size (measured by number of facilities) and Levels of chloroform*
- There is no relationship between PWS system size (measured by number of facilities) and Levels of disinfection byproducts*
- There is no relationship between PWS system size (measured by number of facilities) and Levels of nitrate*
- There is no relationship between PWS system size (measured by number of facilities) and Levels of arsenic*

Larger PWSs typically have access to more resources and larger technical staffs. It is therefore possible that larger PWSs therefore have higher water quality and fewer regulatory violations. Several metrics are available to determine the size of a system. The number of facilities is one determinant of the size of a PWS. Additionally, the population served is another metrics for the size of a PWS.

Data Collection

The quantitative data set for this project was compiled from three separate sources. The first data source, providing information on PWSs, is the EPA SDWIS. Second, the EWG Tap Water Database contains information regarding water quality. Third, the CDC SVI is published to characterize communities across the United States. Data from all three sources were compiled to enable quantitative analysis to evaluate the hypotheses set forth in this study.

Quantitative Analyses to be Performed

Source Water Type vs Parameters

This analysis is based on a two-tail z-test for comparing two means. Steps are as follows:

- Step 1: Determine descriptive statics: average, median, standard deviation, number of samples
- Step 2: Select a significance level (α)
    - Note: This study utilizes $\alpha = 0.05$
- Step 3: Calculate the z-score, where:

$$z = \frac{x_1 + x_2 - \Delta}{\sqrt{[(\sigma_1^2/n_1)+(\sigma_2^2/n_2)]}}$$

- z = z-score
- x_1 = mean of sample 1
- x_2 = mean of sample 2
- Δ = hypothesized difference between means (0 if testing null hypothesis)
- σ_1 = standard deviation of population 1
- σ_2 = standard deviation of population 2
- n_1 = size of population 1

- n_2 = size of population 2

- Step 4: Determine probability from a z-table and multiply by two, because the test is two-tailed.
- Step 5: Compare the probability to the significance level. If the probability is less than the significance level, then the null hypothesis is rejected. Otherwise, the null hypothesis fails to be rejected.

Social Vulnerability, PWS Population, and PWS Number of Facilities vs Parameters

This analysis is based on Pearson's correlation coefficient, used to measure the relationship between two variables. Steps are as follows:

- Step 1: Determine descriptive statics: average, median, standard deviation, number of samples
- Step 2: Select a significance level (α)
  - $\alpha = 0.05$
- Step 3: Calculate Pearson correlation coefficient (r)
  - Note: use "PEARSON" function in Microsoft Excel
- Step 4: Determine number of pairs of data (n)
- Step 5: Calculate degrees of freedom (n-2)
- Step 6: Calculate the t-statistic (t)

$$t = \frac{r * \sqrt{(n-2)}}{\sqrt{(1-r^2)}}$$

  - t = t-statistic
  - r = Pearson correlation coefficient
  - n = Number of pairs of data

- Step 7: Determine the probability p-value (p)
    - Note: use "TDIST" function in Microsoft Excel (within Excel x = t and input 2 tails)
- Step 8: Compare the probability to the significance level. If the probability is less than the significance level, then the null hypothesis is rejected. Otherwise, the null hypothesis fails to be rejected.

Expected Outcome

This case study seeks to identify potential resources and methodologies by which communities may collectively improve their ability to mitigate, prepare, respond, and recover from drinking water-related emergencies. It is proposed that gaps may be identified. It might also be possible that areas for increased collaboration between emergency managers and the drinking water industry will be identified. The quantitative analyses are expected to determine the utility of water industry meta-data. If relationships between key variables are identified, then risk-reduction recommendations could be generated or future research opportunities could be proposed.

Limitations

There are a number of limitations that apply to this case study. First, the literature review and the databases that form the basis of the quantitative portion of this study are limited to publicly available resources. Second, the databases that are utilized as part of the study each have internal limitations. For example, the SDWIS database relies on input from state-level regulators. Third, the researcher did not have access to internal stakeholders within PWSs, state regulatory agencies, or federal agencies. These limitations are likely to contribute to the need for further research upon completion of this case study.

Methods Summary

The methods of this case study are designed to answer the research question: How can emergency managers improve risk reduction efforts associated with drinking water infrastructure through analysis of practices and meta-data within the emergency management literature? In order to frame the question, a conceptual framework is presented. The conceptual framework visually displays the relationships between PWSs and both their dependent and independent variables. A description of source information is then provided. First, it is acknowledged that the answer to the research question stems from the work of previous scholarly output. In addition, quantitative data sources from three databases are described. The remainder of the methodology section describes how the source materials could be used to answer the research question.

The methods section describes the compilation of the data set. The source data is derived from three different databases. An EPA database lists groundwater type, number of violations, and size-related data associated with each PWS. A database from a non-profit organization provides data regarding water quality for each large PWS serving over 10,000 consumers. A third database is provided by the CDC to identify the SVI of the county in which each PWS is located. A single database was compiled to merge data from each of the three listed databases.

The hypotheses are presented as well as the statistical techniques that are used to evaluate the data. The presentation of the hypotheses provides an overview of potential relationships between variables. The display of the statistical techniques discloses the methods by which the data is analyzed. The presentation of the hypotheses and quantitative analysis techniques may facilitate future studies that could be conducted to build upon this case study. The expected outcome of this study is to identify methods by which water-related disasters could be minimized in the future. The methods section also includes a discussion of the limitations of the study. All computations were performed using Microsoft Excel.

Quantitative Results

Quantitative results were produced for two different states: Illinois and Texas. The results are presented below, based on the independent variables. The availability of results from two different states helps illuminate the relationships between the respective dependent and independent variables. Future studies may expand on the datasets to include all states, territories, and tribal lands. Many of the relationships between variables were consistent between Illinois and Texas, although some diverged.

Hypothesis 1: Social Vulnerability Index vs Parameters

Table 1

Hypothesis Group 1: Social Vulnerability Index v. Parameters

Independent Variable	Dependent Variable	PWSs Analyzed	Illinois		Texas	
			Significant difference?	Relationship	Significant Difference?	Relationship
SVI	Quantity reguator site visits	All	Yes	Proportional	Yes	Proportional
	Regulator site visits per capita	All	No	None	No	None
	Quantity regulatory violations	All	Yes	Proportional	Yes	Proportioanl
	Regulatory violations per capita	All	No	None	Yes	Proportional
	Number of contaminants exceeding health guidelines	Large*	Yes	Proportional	No	None
	Levels of arsenic	Large*	No	None	Yes	Proportional
	Levels of chloroform	Large*	No	None	No	None
	Levels of nitrate	Large*	Yes	Porportional	Yes	Proportional
	Levels of disinfection byproducts	Large*	No	None	No	None

Note. *Large systems serve 10,000 or more consumers.

SVI was first evaluated in comparison to the PWS population served. In the state of Illinois, a larger population served was proportional to a higher SVI. For Illinois, the p-value for the Pearson's correlation coefficient test was $6.48 * 10^{-9}$. In contrast, the p-value for the Pearson's correlation coefficient test for Texas was 0.23, which is not statistically significant. The data was suggestive that in Illinois larger communities have a higher SVI, while in Texas

SVI is more evenly distributed based on population size. In other words, poverty and other social ills may be more concentrated in Illinois than in Texas. Given the difference between the results from different states, the suggestion is that some states may have a relationship between population served and SVI, while others do not. Future research that evaluates data on a national level might more definitely delineate the relationship between population served and SVI.

SVI was next compared to the quantity of regulator site visits as well as the quantity of regulator site visits per capita. Initially, it was not known whether elevated SVI would correlate to more attention from regulators. Would regulators provide more attention to well-off areas or disadvantaged areas? The data regarding the total number of site vests indicated that higher SVI communities receive more visits. The p-value for the Pearson's correlation coefficient test for Texas was $4.05 * 10^{-24}$ and for Illinois it was $7.2 * 10^{-56}$, both indicating statistically significant relationships. Alternately, for visits per capita, there was no statistically significant relationship in Texas or Illinois, with p-values of 0.22 and 0.16, respectively. This indicates that, on a per capita basis, the relative SVI of a PWS does not seem to influence the quantity of regulator site visits.

The first potential anomaly with the Hypothesis 1 data set that deserved attention involved a potential data discrepancy associated with system size. SVI is related to number of site visits on an absolute basis in both states, and is simultaneously not related to per capita number of site visits in either state, indicating that there should be a relationship between population size and SVI. This is true in Illinois where the population served was directly proportional to SVI. However, in Texas, there was no relationship between SVI and population served. This anomaly could best be overcome with future research analyzing all available data on a national level.

SVI was also compared to the total number of regulatory violations as well as the quantity of violations per capita. Higher-SVI systems received more violations in both Texas and Illinois, with p-values from Pearson's correlation coefficient test of $1.56 * 10^{-6}$ and 0.03, respectively. The split between Texas and Illinois with respect to violations per capita is a potential second anomaly with the Hypothesis 1 data set. In Texas, higher-SVI systems were more likely to receive regulatory violations on a per capita basis. In Illinois, there was no relationship between SVI and the number of violations per capita. In Texas and Illinois, the SVI to regulatory violation p-values from the Pearson's correlation coefficient tests were, respectively, 0.02 and 0.05. The 0.05 p-value for Illinois was nearly low enough to indicate a relationship, which seems to resolve the apparent anomaly. A future study, with national-level data, would provide more conclusive findings.

There was a significant positive relationship between SVI and the number of contaminants exceeding EWG health guidelines in Illinois (p-value = 0.02). However, there was no such relationship in Texas (p-value = 0.14). There was no relationship between SVI and chloroform in either Illinois or Texas, with p-values of 0.33 and 0.98, respectively. Likewise, there was no relationship between SVI and levels of disinfection byproducts in either Illinois or Texas, with respective p-values of 1.01 and 0.41. In Texas, there was a positive relationship between levels of arsenic and SVI, with a p-value of 0.00. Alternately, in Illinois there was no relationship between SVI and arsenic, with a p-value of 0.09. There was a relationship between SVI and nitrate in both Illinois and Texas, with respective p-values of 0.01 and 0.00.

The third and fourth potential anomalies with the Hypothesis 1 data set related to why the Illinois and Texas data differed with respect to the relationship between SVI and both the number of contaminants exceeding health guidelines and arsenic. In Illinois there was a significant relationship between SVI and number of contaminants exceeding health guidelines while there was no such relationship in Texas. Alternately, Texas experienced a relationship between SVI and arsenic while there was no such relationship in Illinois. The best method to explore these anomalies would be to conduct a future study utilizing national-level data.

Hypothesis 2: Source Water Type vs Parameters

Table 2

Hypothesis Group 2: Source Water Type v. Parameters

Independent Variable	Dependent Variable	PWSs Analyzed	Illinois		Texas	
			Significant difference?	Relationship	Significant Difference?	Relationship
Source Water Type	Quantity reguator site visits	All	No	None	No	None
	Regulator site visits per capita	All	No	None	No	None
	Quantity regulatory violations	All	No	None	No	None
	Regulatory violations per capita	All	No	None	No	None
	Number of contaminants exceeding health guidelines	Large*	No	None	No	None
	Levels of arsenic	Large*	No	None	No	None
	Levels of chloroform	Large*	No	None	No	None
	Levels of nitrate	Large*	No	None	No	None
	Levels of disinfection byproducts	Large*	No	None	No	None

Note. *Large systems serve 10,000 or more consumers.

The data indicated that there was no relationship between source water type and the parameters. In other words, source water type had no relationship to either regulatory violations or water quality. The absence of relationships was, in itself, an interesting finding. The absence of relationships indicated that modern administrative and technical systems are sufficient to overcome the increased challenges of treating surface water. These findings indicated that future research should focus more on SVI and system size than ground water type.

Hypothesis 3: PWS System Size (population served) vs Parameters

Table 3

Hypothesis Group 3: PWS System Size (measured by population served) v. Parameters

Independent Variable	Dependent Variable	PWSs Analyzed	Illinois		Texas	
			Significant difference?	Relationship	Significant Difference?	Relationship
System Size (Population Served)	Quantity reguator site visits	All	Yes	Proportional	Yes	Proportional
	Regulator site visits per capita	All	Yes	Inverse	Yes	Inverse
	Number of violations	All	Yes	Proportional	No	None
	Number of violations per capita	All	Yes	Inverse	No	None
	SVI	All	No	None	No	None
	Number of contaminants exceeding health guidelines	Large*	No	None	Yes	Proportional
	Levels of arsenic	Large*	Yes	Inverse	No	None
	Levels of chloroform	Large*	No	None	No	None
	Levels of nitrate	Large*	No	None	No	None
	Levels of disinfection byproducts	Large*	No	None	No	None

Note. *Large systems serve 10,000 or more consumers.

The data showed that larger systems, measured by number of facilities, received more regulatory attention, in the form of site visits. P-values were 0.00 and $5.22 * 10^{-29}$ for Illinois and Texas, respectively. In addition, the quantity of site visits per capita were both statistically significant in Illinois and Texas, with p-values of $2.75 * 10^{-80}$ and $4.87 * 10^{-6}$, respectively. As would have been predicted by the literature, smaller systems received more regulatory attention on a per capita bases. The data does not indicate that further research into these relationships is warranted.

The data also indicated that there was no relationship between system size and SVI, with p-values of 0.76 and 0.23 for Illinois and Texas, respectively. Illinois data indicated a relationship between system size and regulatory violations on an absolute and per capita basis, with respective p-values of $1.77 * 10^{-6}$ and $6.39 * 10^{-46}$. As would have been predicted by the literature, smaller systems received more attention on a per capita basis. The first potential anomaly in the data was represented by the fact that the Texas data differed from Illinois in that there were no relationships between system size and either the absolute number of violations or violations per capita, with p-values of 0.30 and 0.08, respectively. The potential anomaly could be resolved by future research that utilizes national-level data.

The data indicated that there were no relationships in Texas or Illinois between system size and chloroform, nitrate, or disinfection byproducts. However, as would be predicted by the qualitative literature, there was an inverse relationship with respect to arsenic in Illinois, with a p-value of 0.04. A second potential anomaly with the Hypothesis 3 data is that while this relationship existed in Illinois, there was no relationship between system size and arsenic in Texas. This potential anomaly could be resolved through future research that involves analyzing national-level data.

A third potential anomaly with Hypothesis 3 data was that there was a relationship between system size and number of contaminants exceeding health guidelines in Texas but not in Illinois, with p-values of 0.01 and 0.18, respectively. This anomaly could likely be resolved with future data utilizing national-level data. However, a more problematic fourth anomaly also presented itself with these same data points. The qualitative literature indicated that there should be fewer contaminants exceeding health guidelines in larger systems, while the data for Texas showed the opposite. A future study utilizing national-level data may provide some insight into this finding. However, the inconsistency with the qualitative literature also calls into question the reliability of the underlying data.

The underlying data came from a third-party non-profit organization that relies largely on publicly available data. It is possible that larger systems have more data available, which gives the appearance that more contaminants exceed guidelines. Smaller systems may therefore be under-represented in the underlying data. However, it is also possible that the data is accurate, and that other factors may be contributing to increased levels of contaminants in the larger systems. For example, if industrial water contamination sources are more prevalent in larger communities, then it may contributed to decreased water quality.

Hypothesis 4: PWS System Size (number of facilities) vs. Parameters

Table 4

Hypothesis Group 4: PWS System Size (measured by number of facilities) v. Parameters

Independent Variable	Dependent Variable	PWSs Analyzed	Illinois		Texas	
			Significant difference?	Relationship	Significant Difference?	Relationship
System Size (Number of Facilities)	Quantity reguator site visits	All	Yes	Proportional	Yes	Proportional
	Regulator site visits per capita	All	Yes	Inverse	Yes	Inverse
	Number of violations	All	Yes	Proportional	No	None
	Number of violations per capita	All	yes	Inverse	Yes	Inverse
	SVI	All	No	None	Yes	Proportional
	Number of contaminants exceeding health guidelines	Large*	Yes	Proportional	Yes	Proportional
	Levels of arsenic	Large*	No	None	No	None
	Levels of chloroform	Large*	No	None	No	None
	Levels of nitrate	Large*	Yes	Inverse	Yes	Inverse
	Levels of disinfection byproducts	Large*	No	None	No	None

Note. *Large systems serve 10,000 or more consumers.

System size, measured by the number of facilities, was proportional to the quantity of regulator site visits in both Illinois and Texas, with p-values of 0.00 and $9.88 * 10^{-132}$, respectively. In addition, the system size and regulator site visits per capita were inversely proportional in both Illinois and Texas, with p-values of $2.74 * 10^{-80}$ and $3.12 * 10^{-30}$, respectively. These findings are consistent with what would be expected in accordance with the qualitative literature.

A first potential anomaly for Hypothesis 4 appears because in Illinois there is a proportional relationship between system size and number of violations, with a p-value of $1.76 * 10^{-6}$ while there is no statistical relationship in Texas, with a p-value of 0.61. This anomaly could be resolved through a future study utilizing a national-level data set. As would be expected by a review of the qualitative literature, there is an inversely proportional relationship between system size and number of violations per capita in both states. P-values for Illinois and Texas were $6.39 * 10^{-46}$ and $6.00 * 10^{-6}$, respectively. There was a proportional relationship between system size and SVI in Texas, with a p-value of 0.03, although there was no relationship in Illinois, with a p-value of 0.76. This second potential anomaly, the difference in SVI relationships between Texas and Illinois, could likely be resolved by a future study utilizing national-level datasets.

No relationships were identified between system size and arsenic, chloroform, or disinfection byproduct levels in either Texas or Illinois. There are statistically significant inversely proportional relationships in both Illinois and Texas between system size and nitrate levels. For nitrate levels, the p-value in Illinois is 0.01 and in Texas it is 0.02. In both Illinois and Texas there were significant relationships between system size and number of contaminants exceeding health guidelines. The p-value in Illinois was 0.02 and in Texas it was also 0.02. This data represents a third potential anomaly with Hypothesis 4 because the qualitative literature would predict that the relationship should be inversely proportional, rather than proportional. This could be because of problems with the underlying data. Alternately, it could indicate that previous assumptions regarding the relationship between system size and water quality could require revision.

Discussion

This case study utilized a literature review and quantitative techniques to determine how to better engage in drinking water mitigation, preparation, response, and recovery. An extended literature review was able to identify technical and administrative guidance in the literature. Such guidance applies to different audiences, such as drinking water consumers, primacy agencies, and states, local governments, and water systems. Additionally, the quantitative portion of the study was able to elicit a determination as to whether the hypotheses discussed in the methods section were rejected or failed to be rejected.

Technical and Administrative Guidance in the Literature

Bushe (2009) highlighted the need for successful organizational learning, in order to help "groups, large and small, learn from their collective experience (p. 19)." Toward that goal, the literature included both technical and administrative guidance to water operators to promote resilient systems. The guidance related to mitigation, preparedness, and response. Technical and administrative guidance within the literature has the potential to serve as a basis for institutional knowledge that can be shared throughout the drinking water industry.

Various authors have prepared a body of documents that provide technical guidance to the water industry. In particular, response-based documents were geared toward immediate actions after an incident presents itself. However, other technical guidance focused on mitigation and preparedness with an emphasis on administrative techniques. A survey of this literature may be utilized to better understand methods to reduce human health risks associated with drinking water systems.

The concept of organizational learning is challenging when applied to an entire industry. The drinking water industry is much larger than individual stakeholders such as PWSs, regulators, or personnel. The federal government, as a stakeholder, is somewhat unique within the drinking water industry. The federal government serves multiple functions such as a knowledge repository, an issuer of regulations, and it also retains many enforcement and response authorities. Complicating the issue, in 49 states it is state governments that retain primacy for enforcement of the SDWA. In Flint, Michigan, state regulators were not successful in preventing the 2016 disaster in the city of Flint. A review existing guidance designed to bridge knowledge gaps may reveal insight into knowledge-sharing functions and reveal gaps in knowledge.

This study analyzed emergency management-related technical and administrative guidance from the literature geared toward different audiences. The audiences include the following: drinking water consumers, primacy agencies, and states, local governments, and water systems. Drinking water consumers are the private citizens and businesses that utilize potable water from municipal sources. Primacy agencies are governmental entities that are responsible for enforcing the SDWA. States, local governments, and water systems are entities that are typically involved in the production and distribution of drinking water. The review presented below attempts to distill the key points of the literature for each audience.

Drinking Water Consumers

Private citizens are advised to store “at least one gallon per person, per day,” ideally to cover a two-week period (FEMA, 2004, p. 7). The stored water would be used during emergencies for both hydration and personal hygiene. Therefore, for example, a household of four could fulfill this requirement by having 25 cases of bottled water on hand, assuming 12-ounce containers with 24 containers per case. Families may lower risk by storing water in a climate-controlled setting and ensuring stock rotation.

Private citizens are also expected to follow all drinking water-related guidance from their purveyor and governmental authorities. A relatively common recommendation made to consumers is to boil water. Boiling water has the ability to reduce risk associated with microbial contamination. Such guidance may come in the form of an *advisory* or *notice*. The CDC (2016) published a guide that describes various phrases and types of communication that can be used to inform water consumers of risks and either recommended or required precautions.

A 2021 winter storm in Texas highlighted a potential problem for consumers. In Austin, for example, a boil water notice was issued (Austin Water, n.d.). A challenge for many consumers across the state, many of whom were dealing with boil water orders, was that they also had no electricity available. Consumers had unlimited tap water, although they were required to boil it and did not have access to electricity. Alternate methods of water disinfection utilize household bleach, iodine tables, or calcium hypochlorite (Department of the Army Headquarters, 2015).

The federal government has been instrumental in promulgating guidance for drinking water consumers during emergencies. EPA (2017) issued guidance for consumers on how to perform emergency disinfection of drinking water. The EPA also referred to a joint FEMA and American Red Cross publication titled *Food and Water in an Emergency* (2004). Additional guidance for consumers can be found in Appendix B of the Centers for Disease Control *Drinking Water Advisory Communication Toolbox* (2016). The technical aspects of water disinfection were generally consistent, although there were several issues that could potentially generate confusion.

The first potential area of confusion is that the guidance documents do not clearly describe the authorities who may issue drinking water guidance. The EPA (2017) and FEMA (2004) recommend to seek guidance from "local authorities (p. 1, p. 11)." This can be confusing because two separate types of entities may issue drinking water notifications: federal, state, or local officials with emergency authorities or public or private officials that own or operate a regulated PWS. When the EPA and FEMA direct consumers to check with *local authorities*, it is likely that not all consumers will understand the difference between local officials and water purveyors. Will consumers who purchase water from a regulated PWS understand that they need to check with two different sets of local authorities prior to making a conclusion regarding their water? Federal, state, and officials have responsibility over the whole community, including consumers of PWSs, while water purveyors are only responsible for their own customers. Additionally, most communities have some non-PWSs and many have multiple regulated PWSs.

The second potential area of confusion associated with federal guidance is that the referenced documents did not delineate between declared emergencies and routine governmental operations. The vast majority of drinking water incidents that result in public notification are not declared emergencies. Until 2016, the United States had never declared a federal emergency primarily related to drinking water (FEMA, n.d.). The bifurcated communication channels have potential to sow confusion. One communication channel flows through governmental entities with jurisdiction over the area in question. The second communication channel flows through the water purveyor, which may be a private company. During declared emergencies, these communication channels are ideally streamlined. However, during declared emergencies, advice for consumers may differ depending on their water purveyor—users of household wells may need to follow different advice than users of a municipal water system.

The third potential area of confusion associated with federal guidance is that advice to consumers to disinfect and treat water at home is disjointed and incomplete. According to the CDC, there are four types of notifications from a PWS to the public: informational, boil water, do not drink, and do not use (CDC, 2016). However, EPA (2017) provided guidance on "disinfection (p.1)" of water while FEMA (2004) discussed both "disinfection" and "treatment" (p. 10). Although FEMA advised that treatment is recommended in addition to disinfection, no procedures for *treatment* were offered. Also lacking is a discussion of the relationship between boil water notices and disinfection, as would have been applicable in the 2021 Texas snowstorm, when many residents had no viable methods to boil water.

Business and private organizations also have unique challenges associated with water disruptions, particularly as related to food operations. The resources and planning required for continuity of operations for business is much more complex than for individuals or families. Preparation for such eventualities may be accomplished through formal programs, such as the National Fire Protection Association Standard 1600, Standard on Continuity, Emergency, and Crisis Management (NFPA, 2019). Whether formal or ad hoc processes are used in response, compliance with boil water orders is mandatory. This may require the use of licensed potable drinking water tanker trucks, utilization of pre-washed fruits and vegetables, and increased use of hand sanitizer (Houston Health Department, n.d.).

Primacy Agencies

Drinking water production is an established industry in the United States and around the world. An assumption could be made that municipal professional engineers and commercial vendors that install drinking water systems could be relied upon to install safe systems. In the present, the oversight of new drinking water treatment facilities requires skilled review of proposed designs. Several instances of failure of regulators to assure oversight in the design review of new treatment systems have been documented in the literature.

The first example of problems in the design review of a new treatment system occurred at the Fort Belknap Indian Community (FBIC) Drinking Water Treatment Plant. The tribal government did not have primacy for SDWA enforcement, which made the EPA the primary enforcement agency (EPA, 2013a). In 2007, the FBIC submitted plans for a new system, to the EPA (EPA, 2013a). The EPA contracted with a technical organization to provide a design review. Multiple problems were identified with the design review, and the EPA notified the FBIC of the issues. In 2009, $572,700 in federal funds associated with the ARRA were provided for the project, even though the problems identified by the EPA contractors were not addressed (EPA, 2013a). Upon completion of the project, the plant was not able to maintain "compliance with the SDWA, specifically the Disinfection Byproduct Rule" (EPA, 2013a, p. 3).

The Flint, Michigan disaster in 2015 represents the second example of a primacy agency failing to detect design flaws in a treatment system prior to a plant beginning operations. Paine and Kushma (2016) stated the "Office of the Michigan attorney general…asserts that Flint's external water experts inaccurately declared the system to be operating in compliance with the law and that a Department of Environmental Quality employee also fraudulently certified the Flint water treatment plant (p. 5)." The state government, as primacy agency, had a duty to review plans for the proposed system. Failure to provide a sufficient technical review of a system prior to certification is an error of omission.

The two cited examples were both compounded failures. In each case, technical experts working on behalf of a local municipal entity provided poor quality designs. In the FBIC example, the primacy agency acknowledged they did not have sufficient technical capacity to review the design and therefore contracted out the review. The contracted review accurately detected problems, although the problems were not corrected prior to funding and completing the project. Alternately, in Flint Michigan, the state never detected the design flaws in the proposal submitted by the municipality. There was nothing inherently improper about using the Flint River as a source of drinking water. However, certifying an improperly designed treatment plant to produce water for public consumption led to a public health disaster.

States, Local Governments, and Water Systems

States, local governments, and individual water systems have similar community-wide opportunities to seek mitigation projects associated with drinking water. These entities have the ability to collaborate to utilize a variety of federal funding and finance options. Federal options include: "the EPA's Drinking Water State Revolving Loan Fund, the Water Infrastructure Improvements for the Nation Act grant programs, and the Water Infrastructure Finance and Innovation Act financing program, as well as HUD's Community Development Block Grants" (Wheeler & Carson, 2019, p.1).

Conclusions

This case study sought to identify how emergency managers can improve risk reduction efforts associated with drinking water infrastructure through analysis of practices and meta-data within the emergency management literature. A qualitative review of the literature elicited techniques for different audiences to improve risk reduction efforts. The targeted audience includes drinking water consumers, primacy agencies, and states, local governments, and water systems. In addition, quantitative data from three databases was compiled and analyzed to search for relationships. The existing literature had presented largely qualitative assessments of such relationships. This case study involved quantitative analysis of PWS-related relationships. The most significant conclusions are presented below.

The most significant aspect of this study is that it documents an initial methodology that enables a quantitative analysis of PWS performance. In contrast, previous studies have largely focused on qualitative analysis. This case study presents comprehensive data for two states. Although some interesting conclusions could be drawn from the data, it is apparent that the first step in achieving the full power of this methodology would require a national-level dataset to be developed and analyzed. A second future step would be to publish this methodology in a peer-reviewed publication in order to gain feedback on the procedures and to solicit potential improvements to the methodology. Increasing the underlying dataset to include national-level data and improving the methodology through academic collaboration would result in improvements.

A third technique to improve the methodology, although implausible, would be to enact a national requirement for PWSs to centrally upload all of their water sampling data. This case study relied upon a database developed by an independent non-profit organization that collects sampling data from PWSs. It is possible that larger systems are more likely to make their data publicly available, which would mean they disproportionally have their negative attributes documented. Do smaller systems have fewer problems, or are they simply not publicized as well? The EWG cannot be faulted if their data is imperfect—they are independently funded and have limited resources. If this country would like to better assess its PWS performance, it would not be necessary to mandate any new water sampling. Instead, it could mandate PWSs to upload mandatory sample results to a central data repository. Such a requirement would still be expensive, even though it would not require any additional water sampling.

In general terms, the quantitative portion of this study indicated that source water type is not a factor with respect to PWS performance while SVI and system size are factors. A summary of these findings is qualitatively presented in Table 5 below. In Table 5, the nomenclature *PWS performance* is a term that includes both regulatory violations and negative water quality indicators. The results presented in Table 5 indicated that source water type does not have a significant influence on PWS performance indicators. Increased SVI, however, was shown to be related to increases in both regulatory violations and negative performance indicators. Smaller systems, measured based on number of facilities or population served, resulted in more regulatory violations per capita. Although the data indicated a relationship between system size and negative water quality indicators, the directionality of the results was mixed. Some data indicated larger systems have more negative water quality indicators while other data indicated the opposite. Significantly, all data in Table 5, except as noted with respect to system size versus negative water quality indicators, was consistent with what would have been predicted based upon a qualitative literature review.

Table 5

Summary of Quantitative Data Conclusions

Independent Variable	Relationship to PWS performance?	Negative PWS Performance Indicators	
		Regulatory Violations	**Negative Water Quality Indicators**
Source Water Type	No	N/A	N/A
SVI	Yes	Yes (Higher SVI = more violations)	Yes (Higher SVI = lower quality)
System Size	Yes	Yes (Smaller size = more violations per capita)	Varies*

Note. *Differs from predictions based on qualitative literature review.

The most definitive aspect of the quantitative data review was that source water type was not related to PWS performance or negative outcomes. The literature opened the possibility that surface water may present more opportunities for increased violations or decreased water quality. However, there appeared to be no such relationships. These results indicate that future research should focus on either PWS size or SVI. The fact that source water type is a non-factor with respect to PWS outcomes is an indicator that the water industry is been able to effectively overcome the increased challenges associated with the treatment of surface water.

The data from both Texas and Illinois indicated that elevated SVI resulted in increased regulatory violations. In addition, in Illinois' elevated SVI was related to both an increased number of contaminants exceeding health guidelines and increased levels of nitrate. In Texas, elevated SVI was related to increased levels of both arsenic and nitrate. Therefore, the data indicated that elevated SVI is related to both increases in regulatory violations and lower indicators of water quality. Expanding the study to include national-level data would generate increased face validity of these results.

A future expansion of the underlying data set would need to occur in two separate directions. First, all states territories, and tribal lands would need to be represented. Second, all negative water quality indicators, not just the five used in this study, would need to be incorporated. Prior to building out the dataset, the methodology should be subjected to peer review. It is highly plausible that peer review would result in improved techniques for expanding the data set.

System size, measured by either number of facilities or population served, is likely to result in an increased number of regulatory violations per capita. However, the data was not as straightforward with respect to negative water quality indicators. The data did indicate a relationship between system size and negative water quality indicators. However, the directionality of the results was mixed. For example, some data indicated that larger systems have more problems, while other data indicated that smaller systems have more problems. As previously suggested in this case study, the problem could be a result of data availability problems associated with smaller systems. Additional research would need to be conducted to analyze the precise relationships between system size and negative water quality indicators.

Lastly, the quantitative findings of this study had no significant bearing on Flint, Michigan or the ability to predict future similar scenarios in the future. The emergency declaration in Flint in 2016 occurred during a change-over in the water source for a major city. That is an extremely rare event, as major cities do not frequently change their water sources. The quantitative findings, however, can shed light on the impact of SVI on negative PWS outcomes during routine operations. PWSs in locations with elevated SVI can be assessed using the methodology outlined in this case study. In the future, major engineering projects, such as the one that occurred in Flint, Michigan require increased attention. The qualitative, not the quantitative, portions of this case study may shed light on some potential risk reduction opportunities. For example, this case study presented an example (other than Flint, Michigan) where a primacy agency failed to provide oversight on a significant engineering project.

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